Deterministic Sequential-Color Field Emission Display

via Lithography and Optically Confined Phosphor Microspheres

A Conceptual Design Disclosure

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The inventive concepts described in this document originated with and were developed by the author (courter_baked). This document was drafted with the assistance of an AI language model acting as a writing and technical articulation tool under the author's direction. All substantive technical and design decisions, including the core architecture, process sequence, and novel combinations described herein, are attributable to the human author.

Abstract

This document describes a deterministic flat panel display architecture combining field emission display (FED) technology with sequentially deposited, lithographically patterned phosphor microspheres housed within optically confining metal-shell cavities. Red, green, and blue phosphor elements are placed at precisely defined substrate coordinates through a repeating cycle of bulk sphere deposition, stencil lithographic patterning, selective ablation, and gap filling. The result is a regular, known subpixel grid requiring no post-assembly calibration and fully compatible with standard display signal processing pipelines. At the conclusion of each deposition cycle, a planar laser skim cut opens optical apertures across all subpixels of that color layer before the next cycle begins, ensuring buried layers remain accessible and each aperture is defined while its sphere domes are still exposed at the substrate surface. Core to the architecture is an oblate phosphor microsphere encapsulated within an asymmetric reflective metal shell — thicker on the dome hemisphere, thinner at the base — produced in a single centrifuge-assisted deposition step. This shell geometry provides per-element optical confinement, passive self-orientation during substrate assembly, and electron transparency at the excitation face. This document enumerates an extensive range of contemplated variations and alternative implementations across materials, deposition methods, aperture techniques, and backplane technologies, intended to establish the full breadth of the disclosed concept in the prior art record.

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1. Background and Motivation

Field emission displays have been studied since the 1960s as a potential successor to cathode ray tube technology in flat panel form factors. An FED replaces the thermionic electron gun of a CRT with a dense planar array of cold field emitters that accelerate electrons toward a phosphor-coated anode under an applied potential. Each phosphor element is excited locally, producing light with CRT-like characteristics: deep blacks from per-element off states, fast response from the absence of liquid crystal rotation or organic carrier dynamics, and wide viewing angles from the geometry of phosphor emission.

Despite these characteristics, FEDs have never achieved commercial scale. Historically, the dominant obstacles were maintenance of vacuum integrity across large panel areas, degradation of field emitter tips under ion bombardment, and the difficulty of patterning RGB phosphor subpixels at high resolution without cross-contamination between color channels. As LCD technology matured and OLED emerged, the commercial window for FEDs closed before these challenges were resolved.

FEDs retain theoretical advantages neither LCD nor OLED fully addresses: inorganic phosphors do not suffer organic degradation mechanisms responsible for OLED burn-in and lifetime limitations; electron excitation is decoupled from thermal management constraints affecting organic emitters at high brightness; and phosphor emission spectra can be tuned independently of emitter technology. This document describes a fabrication architecture designed to address the phosphor patterning challenge using an iterative lithographic process adapted from established semiconductor and display manufacturing techniques.

2. Relationship to Existing Technologies

2.1 MicroLED Mass Transfer

The most direct contemporary comparison is the microLED display, in which discrete LED die are fabricated on a growth substrate and transferred to a backplane in precise spatial arrangement using pick-and-place, elastomer stamp transfer, or laser lift-off techniques. The precision requirement for microLED mass transfer is severe: individual die must be placed at target coordinates with sub-micron accuracy at throughputs sufficient to populate a display panel in commercially viable cycle times. The sequential stencil process described in this document operates on a continuous substrate using parallelized area processes rather than serial or batch die placement, which is argued to represent a more favorable manufacturing scaling characteristic.

2.2 OLED Shadow Mask Deposition

OLED RGB patterning commonly uses fine metal masks during organic material evaporation to define which substrate areas receive each color. The stencil lithography step in the proposed process is conceptually similar but applied to selective retention of bulk-deposited phosphor microspheres rather than directional evaporation of organic films. Sphere deposition is not line-of-sight, reducing the shadowing and alignment sensitivity that limits fine metal mask resolution at large panel sizes.

2.3 Phosphor Screen Fabrication

Traditional CRT phosphor screens are deposited by slurry settling, photolithographic patterning, and development. This process does not produce the optical isolation between subpixels

described in this architecture. The metal-shell cavity structure of the proposed microsphere approach is a significant departure, providing per-element optical confinement not present in conventional phosphor screen fabrication.

3. Phosphor Microsphere Design

3.1 Morphology

The fundamental emissive element is a phosphor microsphere: a core of inorganic phosphor material encapsulated within a reflective metal shell. The preferred morphology is an oblate spheroid — wider in diameter than in height — which self-orients flat-face-down under mechanical vibration and packs more efficiently than true spheres. However, the disclosed concept explicitly contemplates true spheres, prolate spheroids, and other rotationally symmetric geometries as functional equivalents. The self-orientation behavior is a preferred property, not a limiting requirement; external orientation mechanisms including electric field alignment, magnetic alignment, or surface chemistry-driven attachment are also contemplated as means of achieving consistent aperture-face orientation.

3.2 Phosphor Core Materials

Phosphor cores are synthesized for each color channel using any suitable inorganic phosphor system excited by electron bombardment. The disclosed concept is not limited to any specific phosphor chemistry. Contemplated red phosphor materials include but are not limited to: Y2O2S:Eu, Y2O3:Eu, Gd2O2S:Eu, CaS:Eu, and nitride-based red phosphors. Contemplated green phosphor materials include but are not limited to: ZnS:Cu,Al, SrGa2S4:Eu, BaMgAl10O17:Eu,Mn, and silicate-based green phosphors. Contemplated blue phosphor materials include but are not limited to: ZnS:Ag, BaMgAl10O17:Eu, and ZnS:Ag,Cl. Quantum dot materials, perovskite phosphors, and other luminescent inorganic materials capable of electron excitation are also contemplated as core materials. The disclosed concept applies equally to any current or future inorganic luminescent material suitable for electron excitation.

3.3 Shell Materials and Deposition

The reflective shell encapsulating each phosphor core may be composed of any reflective metal or metal alloy. Contemplated shell materials include but are not limited to: aluminum, silver, gold, chromium, nickel, copper, titanium, and alloys thereof. The shell may be deposited by any process capable of producing a conformal or directional coating on a particulate substrate, including but not limited to: sputter deposition, electron beam evaporation, thermal evaporation, electroless plating, electroplating, atomic layer deposition, and chemical vapor deposition. Asymmetric shell thickness between dome and base hemispheres may be achieved by centrifugal deposition as described, or alternatively by any directional deposition process, masked deposition, sequential deposition from opposing directions, or post-deposition selective thinning of the base hemisphere by etching, ion milling, or mechanical lapping.

The shell need not be a pure metal. Dielectric mirror coatings — alternating layers of high and low refractive index materials — are contemplated as an alternative to metallic reflection, offering potentially higher reflectivity across the phosphor emission spectrum with lower absorption loss per internal reflection. The shell may also incorporate a transparent conductive layer, such as indium tin oxide, to assist in charge dissipation from electron bombardment.

3.4 Shell Geometry Variants

The asymmetric thick-dome, thin-base shell geometry is the preferred embodiment for FED backplane excitation. However, the disclosed concept explicitly contemplates the following shell geometry variants as functionally equivalent or useful in specific applications: uniform-thickness shells with a separately formed aperture; shells with a pre-formed aperture opening produced during deposition by substrate masking; shells with graded thickness varying continuously from base to dome rather than in discrete thick and thin regions; and multi-layer shells incorporating both reflective and structural layers of different materials.

4. Sequential Color Deposition Process

The phosphor substrate is built through three sequential deposition cycles, one per color channel. The following describes the preferred embodiment; Section 11 enumerates contemplated variations in each step.

4.1 Bulk Sphere Deposition

A suspension or dry powder of monodisperse phosphor microspheres for the current color channel is deposited across the substrate to form a close-packed monolayer with consistent orientation. Vibration-driven self-assembly is the preferred deposition method. Alternative deposition methods explicitly contemplated include: doctor blade coating, spin coating, spray coating, electrophoretic deposition, inkjet deposition, and Langmuir-Blodgett film transfer. Any process that produces a monolayer of consistently oriented microspheres on the substrate surface is contemplated as a functional equivalent to vibration settling.

4.2 Selective Removal of Off-Target Spheres

Off-target spheres — those occupying positions designated for a different color channel — are removed using a photolithographic process. A photoresist layer is applied over the entire monolayer, then exposed through a photomask that defines the target subpixel positions for the current color channel. Development removes resist from non-target positions, leaving those spheres unprotected. The unprotected spheres are then removed by laser ablation, reactive ion etching, wet chemical etching selective to the shell metal, or any other removal process compatible with the embedding medium and retained spheres. Following removal, the resist protecting target-position spheres is stripped, leaving only the current color channel at its designated positions.

Alternative patterning approaches explicitly contemplated include: physical stencil masks analogous to OLED fine metal masks applied prior to deposition or removal; inkjet printing of a protective material directly onto target-position spheres; laser-direct-write exposure of a photosensitive layer; nanoimprint lithography; and any other area-selective protection method capable of defining subpixel-scale features. The mask pattern may define any subpixel layout geometry, including but not limited to: RGB stripe, delta triad, pentile matrix, quad-pixel arrangements, and non-repeating or algorithmically optimized layouts. Removal methods explicitly contemplated include: reactive ion etching, wet chemical etching, ultrasonic agitation, mechanical brushing, tape lift-off, selective dissolution of the embedding medium beneath off-target spheres, and air jet or liquid jet impingement.

4.3 Gap Filling and Planarization

Vacated positions are filled with an inert embedding medium. The preferred embodiment uses spin-on glass. Alternative embedding media explicitly contemplated include: UV-curable epoxy resins, thermally cured polymer resins, sol-gel silica, silicon nitride deposited by CVD, silicon dioxide deposited by CVD or ALD, spin-on dielectrics, black matrix resin compositions used in conventional display manufacturing, and any other material that can fill inter-sphere gaps, cure to sufficient hardness to support subsequent processing, and meet vacuum compatibility requirements for FED operation. The embedding medium may be optically absorptive, reflective, or transparent, with optically absorptive or black matrix compositions preferred for minimizing inter-subpixel light leakage. After curing, the surface is planarized to present a flat substrate for the subsequent deposition cycle.

4.4 Per-Cycle Aperture Definition

Following gap filling and planarization of each color cycle, a planar laser skim cut is made across the substrate surface to open optical apertures in the metal shell domes of the just-deposited color layer. This step must occur before the next deposition cycle begins, while the current layer's sphere domes remain exposed above the planarized surface. Once a subsequent cycle deposits and embeds additional spheres, the earlier layer is buried and no longer accessible for aperture cutting without risking damage to overlying material.

The skim cut for each cycle is performed at a depth determined by the target aperture diameter for that color channel, allowing independent aperture sizing per channel. The embedding medium surrounding the spheres of the current layer must be sufficiently laser-resistant to protect completed lower layers during each successive cut. Material selection for the embedding medium should account for this cumulative laser exposure across all cycles.

4.5 Number of Deposition Cycles

The preferred embodiment uses three sequential cycles for red, green, and blue color channels. The disclosed concept explicitly contemplates any number of deposition cycles, including: two cycles for two-color or complementary-color display applications; four or more cycles for displays with extended color primaries such as RGBW (red, green, blue, white) or RGBY (red, green, blue, yellow) subpixel arrangements; and a single cycle followed by color conversion layers applied to some subpixels as an alternative to separate per-color deposition. The principle of sequential selective deposition and patterning applies to any number of distinct emissive element types.

5. Aperture Definition — Parameters and Variants

Optical apertures are opened in the metal shell dome of each microsphere at the end of the deposition cycle in which it is placed, as described in Section 4.4. The following describes the parameter space and alternative methods contemplated for this step, applicable identically to each per-cycle aperture operation.

Laser parameters: any laser wavelength, pulse duration, and fluence that achieves preferential ablation of the shell metal over the phosphor core material is contemplated. Suitable laser types include but are not limited to excimer lasers (ArF 193nm, KrF 248nm, XeCl 308nm), Nd:YAG and harmonics (1064nm, 532nm, 355nm, 266nm), CO_2 lasers, and ultrashort pulse femtosecond lasers. Femtosecond lasers are explicitly contemplated as offering reduced heat affected zone and more precise depth control than nanosecond pulse systems, and may be

preferred where tight control of cut depth is required to avoid damage to previously completed layers.

Aperture geometry: the planar skim cut produces a circular aperture whose diameter is determined by cut depth and sphere diameter. Non-circular apertures are contemplated and may be produced by multiple intersecting cuts, by masking portions of the sphere dome prior to cutting, or by using a shaped beam profile. Because each color channel is cut in a separate cycle, aperture size is independently specifiable per channel without masking — for example, producing larger apertures for blue subpixels than red to compensate for phosphor efficiency differences — simply by adjusting cut depth per cycle.

Alternative aperture methods: physical sectioning using a dicing saw, wire saw, or lapping process is contemplated as a mechanical alternative to laser cutting. Chemical etching through a planar mask is contemplated as a wet process alternative. Ion milling is contemplated for applications requiring the tightest aperture geometry control. Any process that removes the apex of the dome hemisphere to expose the phosphor core through a defined opening, while leaving previously completed and embedded layers undamaged, is a functional equivalent to the planar laser skim cut.

6. Field Emission Backplane and Alternative Excitation Sources

6.1 Emitter Types

The preferred FED backplane uses carbon nanotube field emitters. The disclosed concept explicitly contemplates all field emitter types, including but not limited to: Spindt-type molybdenum cone emitters, tungsten tip emitters, silicon tip emitters, diamond and diamond-like carbon emitters, boron nitride nanotube emitters, graphene edge emitters, and any other cold cathode field emission structure. The phosphor microsphere substrate architecture is not coupled to any specific emitter technology and is compatible with any electron source capable of exciting the phosphor core through the thin base shell.

6.2 Alternative Backplane Technologies

The disclosed phosphor microsphere substrate architecture is explicitly contemplated for use with excitation sources other than field emitters. Alternative backplane technologies include but are not limited to: conventional thermionic electron gun arrays, low-voltage electron sources, ultraviolet LED arrays (for UV-excited phosphors with transparent shells), and near-UV or blue LED arrays with wavelength-converting phosphor cores. The optical cavity and aperture architecture provides confinement and directionality benefits independent of the specific excitation mechanism, and the sequential lithographic deposition process for creating a deterministic RGB subpixel layout is applicable to any excitation source geometry.

Explicitly, the application of the sequential stencil deposition process to microLED backplanes — where the phosphor microsphere layer acts as a color conversion and optical confinement layer above a blue or UV microLED array — is contemplated and disclosed. This represents an alternative to direct RGB microLED fabrication in which only a single-color (blue or UV) microLED backplane is required, with color generated by the phosphor conversion layer.

6.3 Addressing Schemes

The preferred addressing scheme is a passive matrix row-column drive. Active matrix addressing using thin film transistors (TFT) at each subpixel is explicitly contemplated for improved uniformity and grayscale control. Any addressing topology compatible with the backplane technology is contemplated, including but not limited to: passive matrix, active matrix with amorphous silicon TFTs, active matrix with low-temperature polysilicon TFTs, active matrix with oxide semiconductor TFTs, and active matrix with organic TFTs.

7. Front Glass, Waveguide, and Light Shaping Layer

The aperture face of the completed phosphor substrate presents a planar array of discrete point-like emitters with emission directed predominantly forward through each aperture opening. The optical characteristics of this emission — angular spread, spectral content, polarization state — can be further shaped by a functional front glass or waveguide layer bonded or deposited over the phosphor substrate surface. This section discloses the range of front layer architectures contemplated as part of this display system, each offering different tradeoffs between manufacturing complexity, optical performance, and viewing angle characteristics.

7.1 Conventional Optical Glass

The baseline front layer is a planar borosilicate or aluminosilicate glass substrate serving as a vacuum window and mechanical protection layer. No optical function beyond transmission is required in the preferred minimum embodiment. Anti-reflection coatings applied to the outer surface of the front glass are explicitly contemplated to reduce ambient light reflection and improve perceived contrast. Circular polarizer films laminated to the front glass surface are contemplated as an alternative contrast-enhancement approach, functioning analogously to their use in OLED displays to suppress specular reflection.

7.2 Microlens Arrays

A microlens array (MLA) registered to the subpixel layout of the phosphor substrate is contemplated as a front layer capable of collimating or redirecting emission from each aperture. Each microlens element is aligned to one subpixel aperture and shapes its divergent emission into a more controlled angular distribution. This can increase on-axis luminance at the cost of reduced off-axis brightness, effectively trading viewing angle for peak brightness. Microlens arrays may be fabricated in glass by laser ablation, wet etching, or reflow of photoresist; in polymer by embossing or casting against a master; or in a high-index optical material deposited directly over the phosphor substrate surface. Gradient-index (GRIN) lens arrays are also contemplated as an alternative to surface-relief microlens structures.

7.3 Metalenses

Metalenses — planar optical elements composed of subwavelength-scale nanostructure arrays that manipulate phase, amplitude, and polarization of transmitted light through geometric and material design rather than surface curvature — are explicitly contemplated as a front layer for this display architecture. A metalens array registered to the subpixel grid could perform per-aperture beam shaping, collimation, or chromatic correction functions in a flat layer of negligible thickness compared to conventional refractive optics. Metalenses fabricated in titanium dioxide, silicon nitride, or silicon on a glass substrate are contemplated. The planar geometry of the phosphor substrate surface is well suited to metalens integration, as metalens performance is sensitive to the distance and parallelism between the element and its source. Achromatic

metalens designs capable of simultaneous operation across the red, green, and blue emission bands of the phosphor array are explicitly contemplated, as are designs that apply different phase profiles to different color channels by exploiting wavelength-dependent response of the nanostructure geometry.

7.4 Perovskite and Quantum Dot Wavelength Conversion Layers

A wavelength conversion layer deposited or laminated over the front glass is contemplated for applications requiring spectral narrowing or shifting of phosphor emission. Halide perovskite nanocrystal films — including CsPbBr3 for green, CsPbI3 or mixed halide compositions for red, and related compositions for other wavelengths — are explicitly contemplated as conversion materials capable of absorbing broad phosphor emission and re-emitting at a narrower, more saturated wavelength. Cadmium-based and indium phosphide quantum dot films are also contemplated. These conversion layers would be patterned in registration with the subpixel layout to apply wavelength conversion selectively per color channel, or applied uniformly where a single conversion target is desired. The combination of a wavelength conversion layer with the optically confined microsphere aperture architecture is explicitly disclosed as a means of achieving laser-like spectral purity from inorganic phosphor emission without the coherence artifacts of an actual laser source.

7.5 Waveguide-Based Front Layers

Planar waveguide structures coupled to the aperture array are contemplated for applications requiring light extraction at a controlled angle or for integration with augmented reality optical combiners. In this configuration, emission from each aperture is coupled into a waveguide layer via grating couplers, evanescent coupling structures, or prism elements patterned at each subpixel position, and propagates within the waveguide before being extracted at a defined output angle or location. This architecture is explicitly contemplated for near-eye display applications where the display panel functions as the illumination source for a waveguide-based AR combiner. Diffractive waveguide couplers fabricated in the front glass surface by nanoimprint lithography or direct laser writing are contemplated as the coupling mechanism.

7.6 Electrochromic and Switchable Layers

A switchable optical layer — electrochromic, liquid crystal, or electrowetting-based — laminated over the front glass is contemplated as a means of dynamically controlling viewing angle, apparent aperture size, or privacy characteristics of the display. Such a layer could function as a switchable diffuser, transitioning between a narrow-angle high-brightness mode and a wide-angle lower-brightness mode under electrical control. Polymer-dispersed liquid crystal (PDLC) films and suspended particle device (SPD) films are explicitly contemplated as switchable layer materials compatible with this architecture.

7.7 Combined and Stacked Front Layer Architectures

Any combination of the front layer types described in Sections 7.1 through 7.6 is explicitly contemplated. For example: a metalens array for per-aperture collimation combined with a perovskite conversion layer for spectral narrowing; a microlens array combined with a switchable diffuser for mode-selectable viewing angle; or an anti-reflection coated outer glass over a waveguide coupling layer. The front layer stack is treated as a functional element of the display system architecture, and all combinations of the disclosed layer types, in any order, are included in this prior art disclosure.

8. Generalization to Other Display and Lighting Applications

The disclosed architecture is described in the context of flat panel displays but is explicitly contemplated for application in any device requiring a patterned array of discrete light-emitting elements. Applications explicitly contemplated include but are not limited to: direct-view display panels of any size from wearable microdisplays to large-format signage; projection display light engines where the phosphor array serves as a spatially modulated light source; automotive heads-up display and interior lighting systems; augmented and virtual reality display panels; scientific and industrial imaging systems requiring high-contrast inorganic emitter arrays; and general illumination panels where color mixing from a patterned phosphor array is desired.

The sequential stencil deposition process for creating a deterministic patterned array of optically confined emissive microspheres is disclosed as a general manufacturing technique applicable to any combination of emissive particle type, shell material, excitation mechanism, and substrate geometry. The specific combination of FED backplane with inorganic phosphor microspheres is the preferred embodiment but does not limit the scope of the disclosed concept.

9. Manufacturing Complexity Comparison to MicroLED

MicroLED displays require placement of individual semiconductor die at defined substrate coordinates with sub-micron positional accuracy. A 4K display contains approximately 25 million subpixels; each die must be individually transferred, aligned, and bonded. Current mass transfer technologies achieve throughputs and yields that remain challenging at commercial scale.

The sequential stencil process operates differently. Sphere deposition is a bulk area process: all spheres for a given color are deposited simultaneously across the full substrate. Stencil lithography is a parallelized area process: all target positions for a given color are protected simultaneously by a single mask alignment and exposure. Ablation of off-target spheres can be performed as a raster scan or flood exposure.

The precision requirement in the proposed process concentrates in stencil alignment accuracy and sphere monodispersity. Stencil alignment to sub-micron accuracy over large areas is a solved problem in semiconductor lithography. Sphere monodispersity is a chemical synthesis quality control problem, not a placement problem. The proposed process does not eliminate precision manufacturing requirements — lithographic-grade alignment equipment is required — but it replaces the serial die placement challenge of microLED with parallelized area processes that scale more favorably with panel size and subpixel count.

10. Summary of Disclosed Novel Elements

The following elements are disclosed for the public record. Each is disclosed both individually and in all combinations with the others.

1. Oblate or spheroidal phosphor microspheres with asymmetric metal shell deposition producing differential thickness between dome and base hemispheres, by centrifugal deposition or any directional deposition process, in any reflective shell material, for any inorganic phosphor core chemistry.
2. Vibration-driven or otherwise passively driven monolayer self-assembly of oblate spheroids into a consistent dome-up orientation on a flat substrate, or any equivalent

orientation mechanism achieving consistent aperture-face alignment prior to substrate embedding.

3. Sequential multi-cycle deposition process for patterning multiple distinct emissive microsphere types on a single substrate using any combination of bulk deposition, area-selective protection, selective removal, and gap filling, applied to any number of color channels or emissive element types.
4. Use of stencil lithography, photolithography, or any area-selective masking technique to define the spatial positions of each emissive element type during sequential deposition, producing a deterministic subpixel layout of any geometry.
5. Selective removal of off-target microspheres by laser ablation, etching, mechanical, or any other means following area-selective protection of target-position spheres.
6. Gap filling with any inert embedding medium following selective removal, to produce a mechanically stable substrate supporting subsequent deposition cycles and final processing.
7. Per-cycle planar laser skim cut, or any equivalent planar material removal process, performed at the end of each color deposition cycle while sphere domes remain exposed, opening optical apertures in all subpixels of that color layer before the next cycle buries them, with aperture diameter independently controlled per channel by cut depth.
8. Per-color-channel independent specification of sphere diameter, shell thickness, shell material, and aperture size by processing each color in a separate deposition cycle with independently specified parameters.
9. Application of the sequential stencil deposition process to produce a color conversion and optical confinement layer above a single-color microLED or LED backplane, as an alternative to direct RGB emitter fabrication.
10. Front glass, waveguide, or light shaping layer optically coupled to the aperture face of the phosphor substrate, including but not limited to: planar glass with anti-reflection or polarizer coatings; microlens or GRIN lens arrays registered to the subpixel layout; metalens arrays performing per-aperture phase shaping or chromatic correction; perovskite nanocrystal or quantum dot wavelength conversion layers patterned per color channel; planar waveguide structures with grating or evanescent couplers for angle-controlled extraction; switchable diffuser layers for dynamic viewing angle control; and any stacked combination of the foregoing.

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